Computer Optics Vol. 2, No. 1, pp. 81–83, 1990
Printed in Great Britain

0955-355X/90 $10.00 + 0.00
Copyright © 1990 Pergamon Press plc

APPLICATIONS OF COMPUTER-SYNTHESIZED OPTICAL ELEMENTS

USE OF FOCUSATORS IN LASER ASSISTED MATERIAL PROCESSING

C. F. Ageshin, A. A. Azarov, V. V. Popov and I. N. Sisakyan

Abstract—The paper reports applications of optical elements for targetted laser beam focusing in various fields of industry and medicine. These elements, called focusators by their inventors, focus an irradiance with a known distribution of intensity and phase into a plane curve with the specified distribution of intensity. Focusators were designed and prepared which can be used in heat treatment and alloying of metals and in marking of workpieces. These devices proved to be advantageous compared with the traditional optical systems. They allow for intensity distributions in the focal spot that cannot be obtained by other available methods. Also they offer convenient operation and simpler design of the optical systems. The fabrication technology available at present yields focusators with an energy efficiency of up to 80%.

The growing application of the energy and other properties of lasers in industry, medicine and other fields puts in the forefront ever-new problems of controlling laser radiation. The control of a laser beam is understood as both variation of laser directivity in time and focusing its energy. In response to these needs we have developed optical elements, called focusators, which are capable of focusing an incident beam of known distribution of intensity into a plane curve with a specified distribution of intensity along it, or into a set of points or straight lines [1]. Focusators have been designed and manufactured that concentrate a CO_2 laser beam with Gaussian distribution of intensity into a straight line segment with uniform distribution of intensity along it, into arrays of points in the form of letters, digits, etc. These elements are expected to be used in various applications of lasers. Some of these applications will be discussed below.

Laser heat is widely used in industry for heat treatment and alloying. Laser quenching, for example, can be achieved by heating a workpiece with the beam of a high-power CO_2 laser followed by rapid cooling. This type of quenching results in improved hardness of the surface layer and prevents deformation of the workpiece.

In order to achieve high power densities of light necessary for rapid heating, the laser radiation is brought into a point. This point scans the area to be treated by means of deflecting mirrors that swing according to some specified law. A quenching operation therefore begins with a multiple passage of a focused laser beam [2].

If the laser heat scan overlaps an area that had been quenched previously, a patchy heating and annealing occur, thus the uniform quenching of large areas is not at all easy. To avoid this difficulty we employ an optical element that produces a uniform distribution of laser irradiance along a straight line. Moving the workpiece along the normal to this line of irradiance results in a uniformly quenched strip. Sufficient power densities are achieved by focusing light into a very narrow line.

A similar power density requirement occurs in laser-induced alloying of metals which can be achieved by the laser melting of powder spread over the surface to be alloyed.

To demonstrate the potentialities of energy redistribution into a straight line we prepared a focusator which focuses a CO_2 laser beam with Gaussian distribution of intensity and $w_0 = 16$ mm into a 400-μm wide and 20-mm long line 30 cm distant from the focusing element. This line and the amplitude mask of the focuser are shown in Fig. 1. The observed plot of intensity distribution along the line is presented in Fig. 2. The deviations from the ideal uniform level lie within 10%,

Fig. 1. Amplitude mask of a focuser concentrating laser radiation into a straight line (on the left) with a uniform distribution of intensity along it.

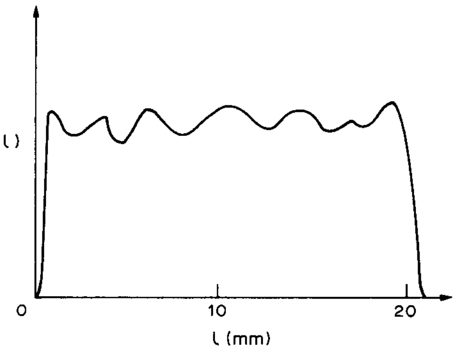

Fig. 2. Experimental distribution of intensity measured along the straight line.

which is allowable in heat treatment operations owing to smoothing of the nonuniform intensity by the thermal conductivity of the metal.

Industrial lasers emit powers up to 5 kW, therefore the optical systems used in conjunction with such light sources must transmit 5 kW of power, and be equipped with the necessary cooling facilities, while remaining convenient to operate.

The galvanos copied from dichromated-gelatin focusers withstand high power densities. In particular we tested a galvano under 1.5 kW of power in the absence of cooling. Copper galvanos provided with cooling withstand 5 kW of illumination for a long time and may be used with advantage in laser hardening and alloying of metals. In addition to focusing, such an element rotates the beam by 90°, i.e. allows elimination of one mirror from the focusing system.

In laser-induced cutting of materials, the high power density requirement can be met by sharp focusing. The spherical lenses used to focus CO_2 laser beams ($\lambda = 10.6\ \mu m$) are not entirely satisfactory. They are made of costly materials, such as ZnSe or GaAs, or environment sensitive materials, such as NaCl and KCl. Moreover, the spherical aberrations of a single lens produce focal spots at least 1–2 mm in diameter.

Applications requiring sharp focusing may be satisfied with a focusator prepared as an analog of an off-axis parabolic mirror. We prepared reflecting focusators that were capable of concentrating a Gauss CO_2 laser beam into a 0.5-mm diameter spot. Simultaneously the focusator rotates the light by 90°, i.e. the rotation and focusing are effected by one element. These devices permit power densities in the focal spot that are sufficient for many cutting and welding applications.

Laser "etching" of material may be used for marking of workpieces. A stencil can be produced by irradiating a workpiece through a mask. This application, however, requires a high power initial beam and has a low efficiency because of the high absorption losses in the mask.In another method free of these disadvantages the beam is scanned through whatever trajectory corresponds to the

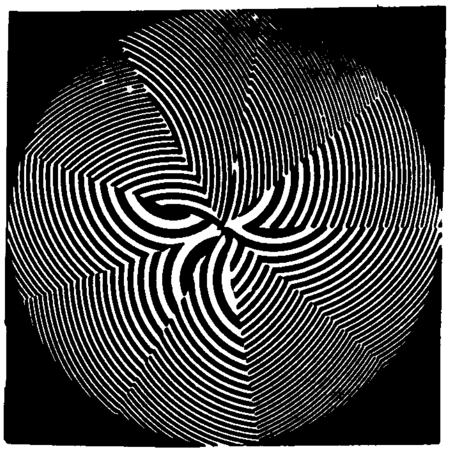

Fig. 3. Amplitude mask of a focusator concentrating the irradiance of a CO_2 laser into a pattern of dots (left).

code character. However, this method, like the aforementioned quenching application, needs a complex scanning facility.

Complex systems of laser radiation control may be replaced by a composite optical element which focuses the incident beam into a set of points or straight lines joining to make a character in the image plane. The procedure is as follows. The surface of the focuser is divided into several parts each of which focuses the radiation into a point appropriately located on the focal plane. The radiation focused at each point changes the structure of the heated material thus producing a marking spot. Replacing the focuser with another one produces another marking spot. The energy efficiency of this method is much higher than that of mask stencilling, because no screens are involved and almost all of the incident light is used.

Figure 3 shows an amplitude mask of an optical element focusing a laser beam into a character (on the left) composed of dots.

The properties of laser light have made lasers very attractive for medical applications. The focused laser beam has proved to be a unique scalpel. In ophthalmology, for example, the laser scalpel is being used to make incisions of special shape to change the radius of curvature. Since the eye is hard to fix in one position it is desirable to make several incisions simultaneously. In response to this requirement we prepared focusators that concentrate the radiation of a CO_2 laser into four radial sections formed into a cross. This figure allows four incisions to be produced simultaneously during one pulse of lasing. Animal experiments have demonstrated that focusators are a promising proposition for ophthalmology [3].

It should be noted that these focusers are not free from certain disadvantages. For example, their efficiency is only up to 80% while the theoretical efficiency is close to 100%. The main cause of this shortcoming is due to an insufficiently accurate fitting of the manufactured relief to the theoretical pattern. This discrepancy results in auxiliary foci receiving part of energy diverted from the specified curve. Any roughness of the focuser surface results in scattering of light. In our subsequent work we intend to improve the accuracy of surface fabrication and enhance the quality of focusing.

REFERENCES

1. A. V. Goncharsky, V. A. Danilov, V. V. Popov, A. M. Prokhorov, I. N. Sisakyan, V. A. Soifer and V. V. Stepanov. Solution of the inverse problem of laser light focusing into an arbitrary curve. *Dokl. Akad. Nauk SSSR* **273**, No. 3 (1983).
2. J. F. Ready. *Industrial Applications of Lasers*. Academic Press, New York (1978).
3. V. S. Akopyan, V. A. Danilov, Yu. K. Danileiko, L. P. Naumidi, V. V. Popov and I. N. Sisakyan. Use of plane axially symmetric focusators for laser surgery in ophthalmology. *Kvantovaya Elektron.* (Moscow) **12**, No. 2 (1985).